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Packet Radio Temporary Note # 90

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# POWER BUDGET ANALYSIS

## 1.0 INTRODUCTION

The power budget for the repeater design is presented in this note. The analysis is similar to Note #4 by Cory; however, this analysis assumes parameters which more accurately reflect the design of the experimental system. Additionally, the question of dynamic range of signal levels is addressed for a given repeater spacing and minimum distance between terminals. The objective is to provide some insight into the allocation of this dynamic range between a transmit power control and the receiver AGC. Sensitivity analysis of this dynamic range to repeater spacing and minimum terminal spacing is included.

## 2.0 ASSUMED SYSTIM PARAMETERS

The following assumptions are made about system parameters for the power budget calculations:

1. Carrier frequency range is 1700 MHz to 1850 MHz.
2. Channel Characteristics:
   Path loss is corrected according to Okumura, et. al. [1] for repeater-terminal links where the repeater antenna

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is assumed to be at 45M height and the terminal antenna at 3M. Free space loss is assumed between repeaters with both antennas at the 45M height. Non-additive white gaussian noise is assumed.

3. Data rate is 100 KB/S for repeater-terminal links and 500 KB/S for repeater-repeater links.
4. The modulation is differential coherent minimum shift keying (DCMSK). For this modulation method, the ratio of hertz per bit is 1.5. This includes 95% of the signal energy.
5. Code spread of 100 for terminal-repeater links and 20 for repeater-repeater links.
6. Noise figure of receiver is 9 db.
7. Antenna gain above isotropic is 0 db for the terminal and 9 db for repeater,
8. The transmitter power amplifier output is 10 watts.
9. The maximum probability of a bit error is $1 \times 10^{-5}$.

## 3.0 THE POWER BUDGET EQUATION

The basic relation for determining the carrier to noise power relation (C/N) is the following equation:

$$C/N \text{ (in db)} = ERP - \text{Path loss} + G_{ra} - 10 \log KT_oB - NF \qquad (1)$$

Where: ERP = Effective radiated power in dbm
$G_{ra}$ = Receive antenna gain
$KT_o$ = Noise spectral density
B = Occupied bandwidth
N.F. = Noise figure of receiver in db

The occupied bandwidth for the assumed system parameters is:

$$B = (\text{Spread Factor}) \times (\text{Data Rate}) \times (\text{Hz/Bit Factor}) = 15 \text{ MHz} \quad (2)$$

for repeater to repeater and repeater to terminal links.

The relation between signal to noise and bit error performance for DCMSK is given in Figure 1. It should be noted that signal to noise is expressed in $E_b/N_o$ where $E_b$ is the energy per bit. Hence, one must convert C/N to $E_b/N_o$. This can be accomplished by multiplying C/N by T (the bit interval) and $E_b/N_o$ by 1/B to yield:

$$\frac{C \cdot T}{N} = \frac{E_b}{N_o \cdot B} \quad (3)$$

so that

$$E_b/N_o = C/N \cdot TB \quad (4)$$

The factor TB can be viewed as the product of the processing gain and the Hz/bit factor. The noise power, N, also has this factor and, therefore, $E_b/N_o$ is independent of the code spread and Hz/bit. The relation for $E_b/N_o$ is then:

$$E_b/N_o = \text{ERP} - \text{Path loss} + G_{ra} - 10 \log KT_oB^1 - \text{N.F.} \quad (5)$$

Where:

$$B^1 = (\text{Data Rate})$$

## 4.0 TRANSMISSION LOSS

The free space loss equation must be altered for the mobile conditions of repeater-terminal links. Okumura provides statistical data for this correction. For the assumed antenna heights, the median path loss per Okumura at 1 mile is approximately 34 db greater than the free space loss. Transmission loss, Okumura corrected, varies with distance at approximately 40 db/decade, compared with free space loss of 20 db/decade. Figure 2 shows the transmission loss for free space versus distance, the median Okumura loss, and the 99% Okumura loss. The 99% line provides insight into the variance of Okumura statistics and is interpreted to be the value for which the probability of the loss at any time being less than or equal to this value is .99.

## 5.0 REQUIRED SIGNAL TO NOISE RATIO

The minimum $E_b/N_o$ for $P_e$ of $10^{-5}$ or less can be obtained from Figure 1. For DCMSK, $E_b/N_o$ must be greater than or equal to 10.4 db.

## 6.0 HYPOTHESIZED REPEATER SPACING

In order to determine the dynamic range of the signal level, one must make assumptions about the repeater spacing and the minimum distance between terminals. The maximum distance between a repeater and terminal using Equation (5) and $E_b/N_o$ of 10.4 db is 1.4 miles for Okumura 99% transmission loss. The spacing between repeaters will be assumed to be equal to this maximum distance to assure full coverage of a given area and provide a minimum of two repeaters being able to cover any terminal location. Figure 3 shows this ideal geometry of repeater spacing ignoring geographical constraints such as mountains, etc. The minimum

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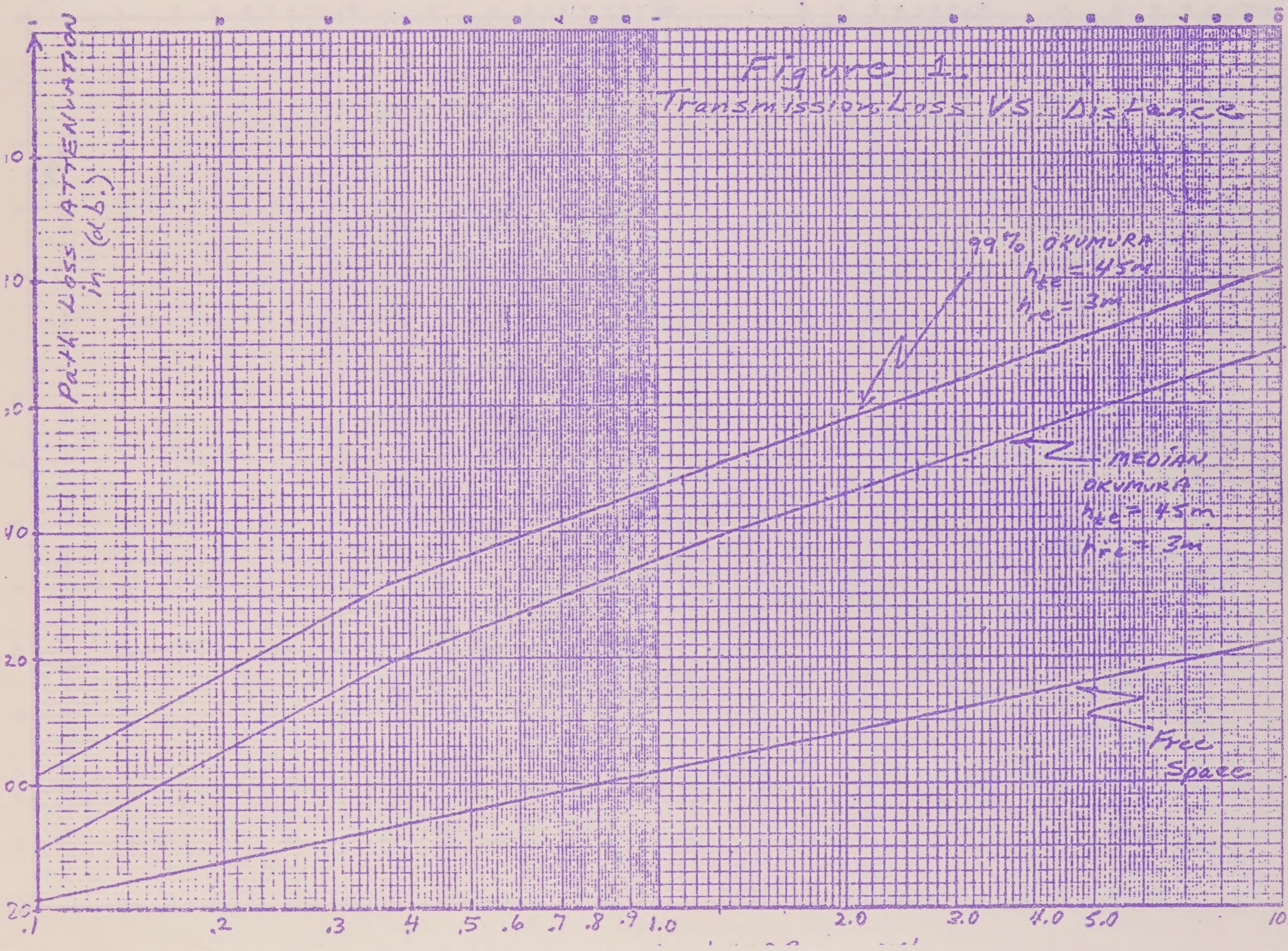
# Figure 1.

## Transmission Loss VS Distance



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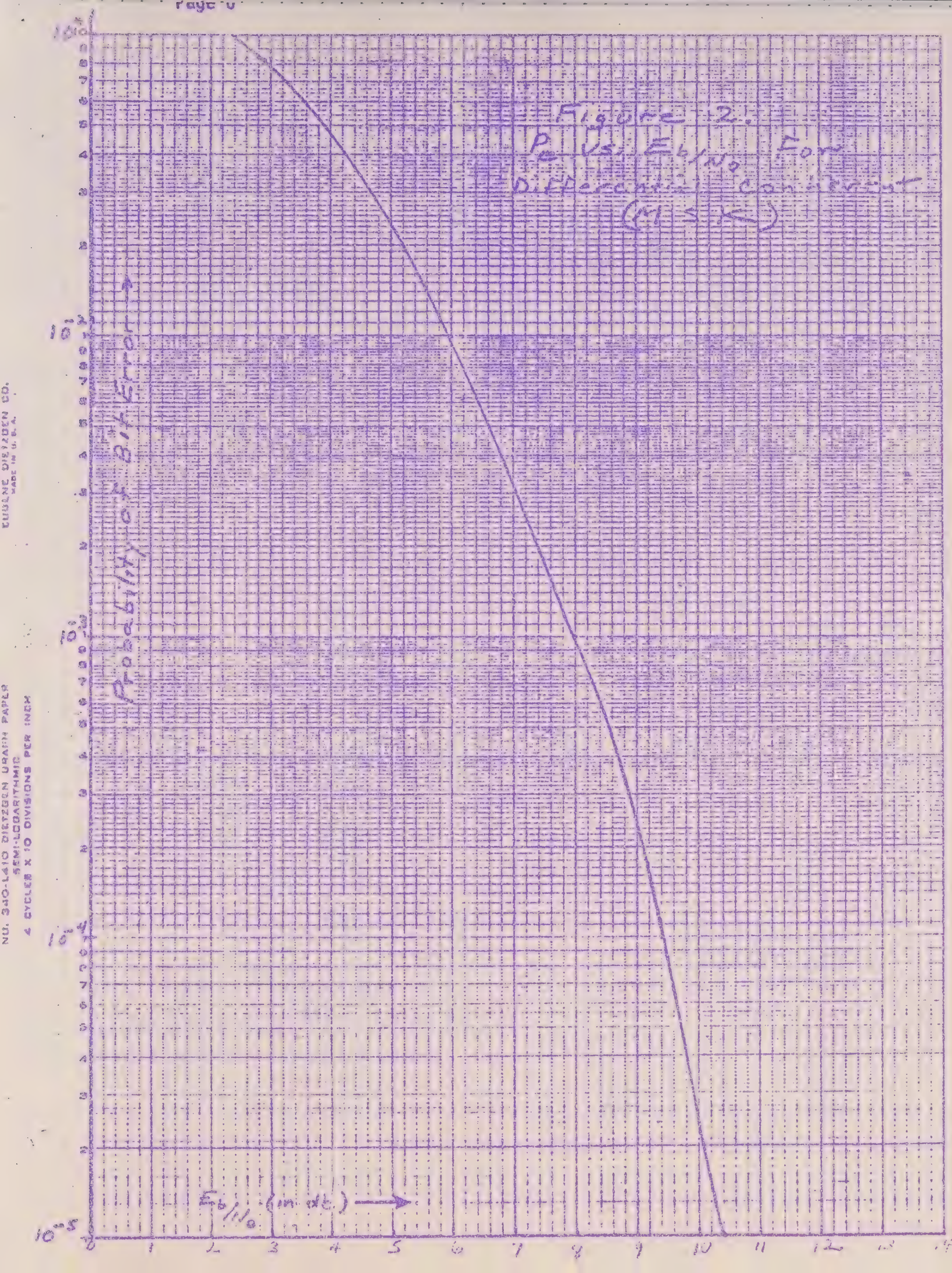


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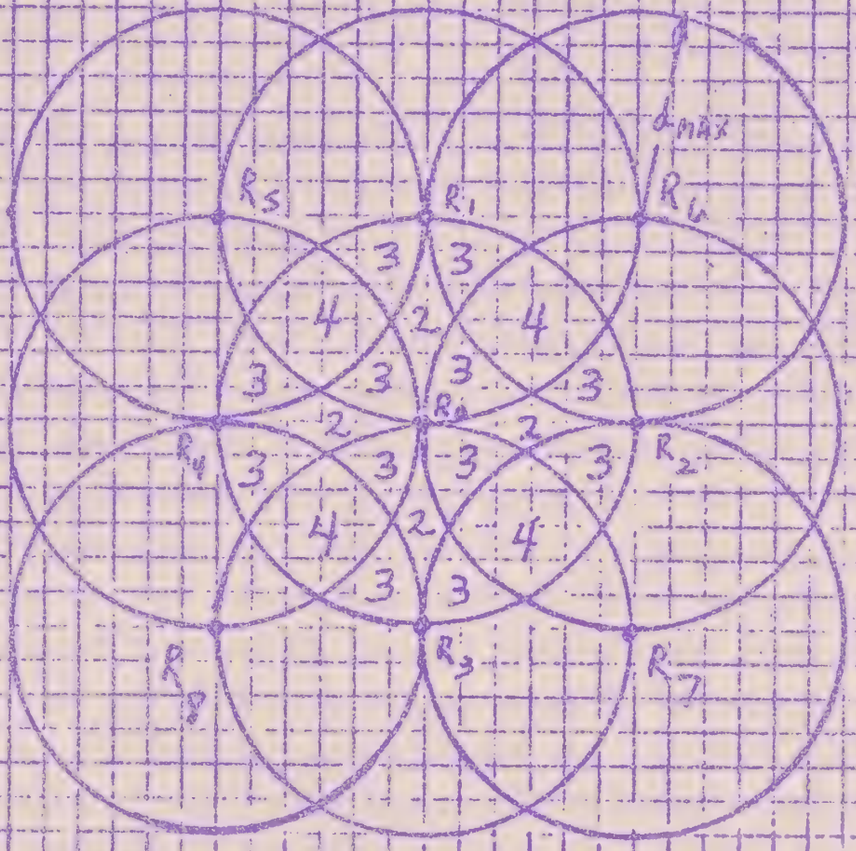


note:

1. $d_{max}$ – maximum Terminal-Repeater link distance

2. Numbers in $R_0$ circle of coverage indicate no. of repeaters covering that area.

Figure 3. Hypothesized Repeater Spacing

distance between terminals is assumed to be 50 feet.

The threshold level of C/N for $E_bN_o$ = 10.4 db is - 11.3 db which means that the signal + noise power is approximately equal to $KT_oB$ or - 102.5 dbm. The maximum received signal power will occur between terminals spaced the minimum distance (50 ft.). In this case, the path loss will be obtained from the free space transmission loss equation. From Equation (1) and the assumed system parameters, the signal power is - 18 dbm. Therefore, the dynamic range of signal energy is 84 db. This dynamic range decreases as the minimum distance between terminals increases at a rate of 6 db/ octave.

If terminals are uniformly distributed radially from a repeater to the maximum distance (1.4 miles), then the average packet from a terminal would originate at .7 mile range. A competing packet from an adjacent repeater would be 33 db above this average terminal packet. The total dynamic range obtained from near to far conditions is independent of repeater spacing since terminal to terminal minimum distance signal level is much greater than repeater-repeater signal levels. It is noted that terminal-terminal packet transfers will not be feasible but represent interfering signals which can force the linear portion of receiver into non-linear operation. One logical allocation of this overall dynamic range between power control and receiver AGC would be to normalize repeater to repeater signal levels to the average terminal packet signal level through power control. This would then require the power control dynamic range to be 33 db for the hypothetical repeater spacing. This would vary with repeater spacing at a rate of 6 db/octave. For example, if the repeaters were spaced $\sqrt{2}$ times the maximum terminal-repeater distance, then the power control range would be 30 db..

The overall dynamic range for a minimum distance between terminals of 50 feet is 84 db, and for the repeater spacing shown in Figure 3, the power control range would be 33 db leaving a minimum dynamic

range of the receiver AGC of 51 db. Additional dynamic range would be necessary to handle pathological cases where the power control was stepped past the normalized level.

## 7.0 CONCLUSIONS

The conclusions that can be drawn from this analysis based on the assumed system parameters are the following:

1. The maximum spacing between repeater and terminal is in the order of one mile.
2. The overall dynamic range of signal levels is independent of repeater spacing and is dependent only on minimum distance between terminals and varies at 6 db/octave.
3. The overall dynamic range for minimum terminal distance of 50 feet is 84 db.
4. An average terminal packet signal level at a repeater will be 33 db below an adjacent repeater packet level.
5. One solution to the large variation between repeater signal levels and terminal signal levels would be to normalize repeater signal level through power control.

The tradeoff in the suggested power control appears to be in the facts that repeaters would not be able to "hop over" repeaters on their way to a station, but repeater packets would not dominate over terminal to repeater traffic. A quantitative comparison as to impact on network system performance (throughput and time delay) is necessary to evaluate this power control scheme.

The path loss study carried on at the University of Hawaii, Note #70, indicated that the path loss vs. distance had the same slope as Okumura's data; however, it was approximately 15 db less in actual loss at 413 MHz. If this was the case, then the maximum repeater-terminal link would be approximately 3.0 miles.

## REFERENCE

1. Okumura, et. al., Field Strength And Its Variability In VHF and UHF Land-Mobile Radio Service, Review of the Electrical Communication Laboratory, Vol. 15, numbers 9-10, September-October, 1968.

## REFERENCE